Secular trends in physical fitness and cardiovascular risks among Chinese college students: an analysis of five successive national surveys between 2000 and 2019

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Summary

Background With increasing concerns about early-onset cardiovascular diseases, it is essential to understand the distribution of cardiovascular health among young adults. This study aimed to characterize trends in physical fitness and the prevalence of overweight/obesity (OWOB), elevated blood pressure (EBP), and their comorbidity among Chinese college students from 2000 to 2019 and to analyze the changes in their associations and subgroup differences.

Methods Data were extracted from five cycles of the Chinese National Survey on Students' Constitution and Health (2000–2019), including 241,710 college students aged 19–22. Physical fitness indicator (PFI) was computed using standardized z-scores of forced vital capacity, sit-and-reach, 50-m dash, standing long jump, muscle strength, and endurance running. OWOB was defined as a body mass index ≥25 kg/m^2, and EBP as systolic blood pressure ≥140 mmHg and/or diastolic blood pressure ≥90 mmHg. Comorbidity was defined as the co-occurrence of OWOB and EBP. Mixed-effects logistic regression was used to analyze associations, and generalized linear mixed-effects models were applied to examine dose-response relationships.

Findings The median of college students' PFI deteriorated continuously from −0.16 in 2000 to −1.99 in 2019, with boys experiencing a faster decline than girls. The prevalence of OWOB, EBP, and comorbidity increased significantly from 3.7%, 2.2%, and 0.3% in 2000 to 14.0%, 5.2%, and 1.8% in 2019, respectively, with boys exhibiting higher prevalence than girls. Decreasing PFI levels were significantly associated with the increasing prevalence of OWOB, EBP, and comorbidity, and such associations were strongest in 2019. L-shaped curves were observed for the relationships between PFI and the prevalence of OWOB, EBP, and comorbidity, with stronger associations in boys. Provincial population attributable fraction showed that when improving the PFI levels from low to middle-low or above, college students in Guizhou, Sichuan, and Yunnan provinces exhibited the most reductions in OWOB, EBP, and comorbidity.

Interpretation Physical fitness among Chinese college students has significantly declined over the past two decades, accompanied by marked increases in the burden of cardiovascular risks. There is an urgent need to increase the focus on college students' health and establish a college-based physical examination system to assess their long-term cardiovascular function.

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Keywords: Cardiovascular health; Obesity; Hypertension; Physical fitness; Youth

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Research in context

Evidence before this study

We searched PubMed using the terms ("college students" [Title] OR "university students" [Title]) AND ("fitness" [Title] OR "obesity" [Title] OR "body mass index" [Title] OR "blood pressure" [Title] OR "hypertension" [Title] OR "cardiovascular" [Title]) for articles published between Jan 1, 2000, and Dec 10, 2024, with no language restriction. Several single-center studies with small sample sizes have reported increasing trends in the prevalence of overweight and obesity (OWOB) and elevated blood pressure (EBP) among college students. However, these studies were often limited to a few college campuses, and their investigation periods typically spanned less than five years. Nationwide representative studies examining long-term trends in the burden of OWOB and EBP among college students over the past decades remain scarce, leaving critical gaps in understanding the cardiovascular health status of this population. Physical fitness has been identified as a shared modifiable factor associated with OWOB and EBP. However, there is a lack of evidence exploring how the relationship between physical fitness and these cardiovascular risk factors has evolved over the years, hindering efforts to assess the stability of these associations and to justify investments in improving physical fitness among college students.

Added value of this study

To our knowledge, it is the first study to use nationwide data to comprehensively examine trends in physical fitness, the prevalence of OWOB, EBP, and comorbidity among college students since the 21st century, filling this population's critical gap in cardiovascular health. Using representative data from the Chinese National Survey on Students' Constitution and Health between 2000 and 2019, we observed an increase in the prevalence of OWOB, EBP, and comorbidity among Chinese college students aged 19–22 years, accompanied by a consistent decline in physical fitness. Boys presented a more severe burden of OWOB, EBP, and comorbidity, as well as poorer physical fitness, while health inequalities among students from different economic regions diminished over time. We identified clear dose-response relationships of physical fitness with the prevalence of OWOB, EBP, and comorbidity, with stronger associations observed in 2019. Furthermore, we identified L-shaped associations of physical fitness with the prevalence of OWOB, EBP, and comorbidity, with stronger linkages observed in boys and in southwest provinces.

Implications of all the available evidence

The rapid economic growth and urbanization in China over the past two decades have coincided with a worsening physical fitness and an increasing burden of cardiovascular risk factors among college students, presenting significant long-term health challenges. These findings underscore the urgency of prioritizing physical fitness in college students through targeted interventions, including enhancing physical education curricula, promoting endurance and aerobic training, and fostering healthy lifestyles. These efforts are particularly critical in resource-poor regions where interventions may yield the most significant impact in reducing the burden of OWOB, EBP, and comorbidities. Most importantly, it is essential to increase the focus on physical fitness and cardiovascular health among college students and establish a college-based physical examination system to achieve long-term assessment of their cardiovascular function.

Introduction

Young adulthood, typically defined as the age range of 18–26 years,[1] is a period usually overlooked yet prone to contributing to health inequalities.[2] The Global Burden of Disease Study reported a rapid increase in the prevalence of cardiovascular disease among individuals aged 20–24 years from 1990 to 2019, with an Average Annual Percent Change (AAPC) of 0.63%, underscoring a concerning trend of earlier onset cardiovascular disease.[3] College students, representing a highly educated youth segment, are vital to a nation's talent pool and future development. College years represent a critical transition period from adolescence to adulthood, when individuals experience considerable shifts from familial dependence to independent self-sufficiency, profoundly changing individual behaviors and contributing to health inequalities in later adulthood.[2,4,5] Furthermore, the pressures of a competitive academic environment, combined with freely structured living conditions on campus, might foster unhealthy lifestyles, exacerbating cardiovascular risk factors.[6,7]

According to the Life's Essential Factors defined by the American Heart Association, weight and blood pressure are fundamental cardiovascular health metrics, regarded as non-invasive and easily monitored indicators.[8–10] Yet, there are few nationwide representative studies investigating trends in the burden of overweight/obesity (OWOB) and elevated blood pressure (EBP) among college students over the past decades, leaving significant gaps in understanding their cardiovascular health status. In addition, given the frequent co-occurrence of OWOB and EBP, their comorbidity gained recognition, with underlying biological mechanisms mainly linked to insulin-mediated stimulation of the sympathetic nervous system.[11,12] However, no study has examined the comorbidity burden of OWOB and EBP among college students.

The most cost-effective strategy for preventing and managing OWOB and EBP is identifying and intervening in the shared modifiable factors. Physical fitness, consisting of cardiorespiratory endurance, muscular endurance, flexibility, and motor ability, was independently associated with OWOB and EBP.[13] Evidence from single-center studies indicated a decline in the physical fitness of college students, particularly in cardiorespiratory and muscular endurance.[14,15] Nevertheless, nationwide representative studies on the trends in physical fitness in college students are still scarce. Furthermore, China has experienced rapid economic development and advancing urbanization since the 21st century, causing significant changes in living environments and a growing diversity of factors influencing OWOB and EBP.[16,17] However, The absence of evidence on the associations of college students' physical fitness with OWOB and EBP over the past decades impedes efforts to evaluate the stability of these associations in evolving contexts, accordingly leading to the future underinvestment to improve physical fitness in college students.

In this study, we aimed to utilize systematic national monitoring data to characterize trends in physical fitness and the prevalence of OWOB, EBP, and their comorbidity among Chinese college students from 2000 to 2019 and to analyze the changes in the associations of physical fitness with OWOB, EBP, and comorbidity across survey years, as well as subgroup differences.

Methods

Study population

Data were extracted from five successive cycles (2000, 2005, 2010, 2014, and 2019) of the Chinese National Survey on Students' Constitution and Health (CNSSCH), the largest nationally representative survey of Chinese child and adolescent health, including college students aged 19–22 years.[18] As described elsewhere, CNSSCH used a multistage stratified cluster sampling procedure to obtain samples aged 19–22 years from colleges in 30 provinces across seven geographic regions, including East (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong), Centre (Henan, Hubei, Hunan), South (Guangdong, Guangxi, Hainan), Southwest (Sichuan, Guizhou, Yunnan, Chongqing), North (Beijing, Tianjin, Shanxi, Hebei, Inner Mongolia), Northeast (Heilongjiang, Jilin, Liaoning), and Northwest (Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang) China.[19] In brief, 2–4 provincial colleges, whose students were mainly drawn from their provinces, were randomly selected from each province; subsequently, classes ranging from freshman to senior years were randomly selected from each selected college; finally, clustered students aged 19–22 years from each selected class were selected to participate in the survey. As shown in Supplementary Fig. S1 and Table S1, a total of 241,710 college students of Han ethnicity were included in our analysis after excluding missing data or biologically implausible values (N = 3567).

The CNSSCH received approval from the Medical Research Ethics Committee of Peking University Health Science Center (IRB00001052–19095). Data collection was conducted in colleges across China, where school principals determined the appropriate method for obtaining informed consent (e.g., written, verbal, active, or passive). Informed consent was secured from all participants prior to initiating the survey.

Data collection

The height, weight, blood pressure, and physical fitness in the CNSSCH were measured by trained staff following a standardized procedure. Height and weight were measured while students were required to wear light clothing and stand barefoot, with height recorded to the nearest 0.1 cm and weight recorded to the nearest 0.1 kg. Blood pressure was measured using an auscultation mercury sphygmomanometer after students sat calmly for at least 10 min. Systolic blood pressure (SBP) was identified at the onset of the first "tapping" Korotkoff sound, and diastolic blood pressure (DBP) was determined at the fifth Korotkoff sound. The average of three SBP (mmHg) and DBP (mmHg) measurements during a single visit were calculated separately for each sample. Six core items of physical fitness were measured, including forced vital capacity (FVC), sit-and-reach (SAR), 50-m dash (SR), standing long jump (SLJ), body muscle strength (MS), and endurance running (ER). FVC, SAR, SR, and SLJ were measured in both boys and girls and recorded to the nearest 1 ml, 0.1 cm, 0.1 s, and 1 cm, respectively. Pull-ups (number) and 1000-m running (s) were assessed in boys to represent MS and ER, while girls were evaluated by 1-min sit-ups (number) and 800-m running.

Indicator definitions

Body mass index (BMI) was calculated as body weight (kg) divided by height squared (kg/m^2). To provide an internationally comparable finding, we used the World Health Organization (WHO) criteria for determining OWOB (BMI≥25 kg/m^2).[20] Given higher percentages of body fat and higher prevalence of cardiovascular diseases in Chinese people than white people at given BMI levels, the threshold for defining OWOB in China was set lower than the international standards.[16] Therefore, we performed Chinese standards as part of our sensitivity analyses, with OWOB defined as BMI≥24 kg/m^2.[16] According to the guideline made by the International Society of Hypertension in 2020, the diagnosis of hypertension should not be made on a single office visit.[21] Thus, SBP≥140 mmHg and/or DBP≥90 mmHg were identified as elevated blood pressure (EBP) to avoid confusion.[22] Comorbidity was defined as co-occurrence of OWOB and EBP. We applied standardized z-scores to assess physical fitness, owing to the absence of globally acknowledged criteria.[18] Taken samples in 2000 as the reference population (Supplementary Table S2), the standardized z-scores of each core item were calculated as an individual item value minus the median, divided by the standard deviation (SD) for that individual's age and sex in the reference population.[18] Then, the physical fitness indicator (PFI) was computed as standardized z-scores of FVC + SAR + (-SR) + SLJ + MS + (-ER).[18] We categorized individual levels of PFI as low (<20th), middle-low (20th–40th), middle (40th–60th), middle-high (60th–80th), and high (≥80th) levels, based on the sex- and age-specific quartiles.[23]

Statistical analyses

Categorical variables were presented as count and percentage, and the Cochran-Armitage trend test was applied to assess the significance of trends in the prevalence of OWOB, EBP, and comorbidity over the years. Given the non-normality proved by the Kolmogorov–Smirnov test, continuous variables were presented as median and interquartile range (IQR), with Jonckheere-Terpstra trend test applying for the trend over the years. Provincial gross domestic product (GDP) for survey years was obtained in the statistical yearbook from the National Bureau of Statistics of China. The provinces were classified into low- (<33rd), middle- (33rd–67th), and high- (≥67th) economic-level regions based on the quartiles of provincial GDP. To quantify the extent of cluster effects from colleges, we calculated the Intraclass Correlation Coefficient (ICC) for OWOB, EBP, and comorbidity at the college level and found that the ICC values were all above 0.1, with the highest exceeding 0.5, indicating significant cluster effects. Thus, we employed mixed-effects models by incorporating both random intercepts and random slopes for colleges, allowing us to account for not only the variability in baseline prevalence of OWOB, EBP, and comorbidity across colleges but also the potential heterogeneity in the associations between predictors and outcomes within each college.

For the associations of physical fitness with OWOB, EBP, and comorbidity, to avoid masking the non-linearity, multinomial logistic regression function in mixed-effects models were selected to analyze the associations, stratified by different survey years. Then, generalized linear mixed-effects models with RCS functions were applied to show the non-linear relationships based on data of all survey years, among which 3-knots RCS were determined according to the lowest Akaike Information Criterion and Bayesian Information Criterion values. Furthermore, population attributable fraction (PAF) was calculated to demonstrate what the prevalence of OWOB, EBP, and comorbidity could be reduced by improving low-level physical fitness to middle-low levels or above, grouped by provinces. Above all analyses were adjusted for the basic demographic variables including age, sex, and GDP, and the cluster effects of colleges. Detailed modeling process were described in Supplementary Text S1 in the Supplementary materials. All statistical analyses were done with R, version 4.3.1.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the manuscript. YS had final responsibility for the decision to submit for publication.

Results

Demographic characteristics

As depicted in Table 1, this study encompassed a total of 49,037 college students aged 19–22 years in 2000, 56,143 in 2005, 47,079 in 2010, 47,266 in 2014, and 42,185 in 2019, of whom 50.0% (120,930) were boys, and 50.0% (120,780) were girls across the five survey years.

Trends in physical fitness from 2000 to 2019

Trends in physical fitness among Chinese college students from 2000 to 2019 were presented in Fig. 1 and Supplementary Table S3. The PFI of college students deteriorated continuously from −0.16 (−2.39, 1.96) in 2000 to −1.99 (−4.71, 0.56) in 2019 (*P-trend* < 0.001), with the distribution curves indicating that boys experienced a faster decline than girls, and the disparities in different economic regions diminished. Among the six components of physical fitness, SLJ, MS, and ER exhibited an observable decline in both sexes, with boys experiencing a more rapid deterioration than girls. In contrast, girls showed an improved trend in SAR.

Trends in the prevalence of OWOB, EBP, and comorbidity from 2000 to 2019

Fig. 2 and Supplementary Tables S4 and S5 showed the trends in the prevalence of OWOB, EBP, and comorbidity in Chinese college students, which increased significantly from 3.7%, 2.2%, and 0.3% in 2000 to 14.0%, 5.2%, and 1.8% in 2019, respectively (*P-trend* < 0.001). The percentages of EBP in the OWOB population continued to grow from 8.2% in 2000 to 12.8% in 2019 (*P-trend* < 0.001). In terms of the prevalence differences between 2019 and 2000, boys exhibited higher prevalence differences for OWOB (boys: 15.1%; girls: 5.8%), EBP (boys: 4.6%; girls: 1.6%) and comorbidity (boys: 2.6%; girls: 0.4%) compared to girls. Mixed-effects logistic regression models proved that boys consistently exhibited a higher prevalence of OWOB, EBP, and comorbidity than girls from 2000 to 2019, with prevalence in boys in 2019 being 2.83 (2.63, 3.06), 4.61 (3.90, 5.45), and 8.23 (6.04, 11.22) times than those in girls, respectively. In addition, mixed-effects logistic regression models supported the fact that the differences in the prevalence of OWOB (middle-level GDP: OR = 1.17 [0.96, 1.42]; high-level GDP: 1.23 [1.00, 1.53]), EBP (middle-level GDP: OR = 0.72 [0.41, 1.27]; high-level GDP: 0.96 [0.63, 1.48]), and comorbidity (middle-level GDP: OR = 0.86 [0.47, 1.57]; high-level GDP: 1.18 [0.70, 1.97]) among three economic regions disappeared

Variables	2000 (N = 49,037)	2005 (N = 56,143)	2010 (N = 47,079)	2014 (N = 47,266)	2019 (N = 42,185)
Age (years)					
19[a]	13,059 (26.6)	14,856 (26.5)	11,820 (25.1)	11,878 (25.1)	10,720 (25.4)
20[a]	12,700 (25.9)	14,555 (25.9)	11,858 (25.2)	11,863 (25.1)	11,029 (26.1)
21[a]	12,480 (25.5)	13,945 (24.8)	11,818 (25.1)	11,893 (25.2)	10,810 (25.6)
22[a]	10,798 (22.0)	12,787 (22.8)	11,583 (24.6)	11,632 (24.6)	9626 (22.8)
Sex					
Boys[a]	25,146 (51.3)	27,864 (49.6)	23,447 (49.8)	23,561 (49.8)	20,912 (49.6)
Girls[a]	23,891 (48.7)	28,279 (50.4)	23,632 (50.2)	23,705 (50.2)	21,273 (50.4)
Height (cm)[bc]	164.20 (158.30, 170.00)	165.00 (159.00, 171.00)	165.70 (159.80, 172.20)	166.00 (159.80, 172.50)	166.70 (160.10, 173.30)
Weight (kg)[bc]	54.40 (49.50, 60.20)	55.00 (49.70, 61.00)	55.60 (50.00, 62.90)	56.40 (50.40, 64.20)	58.10 (51.30, 67.00)
Body mass index (kg/m^2)[bc]	20.17 (18.89, 21.69)	20.18 (18.90, 21.71)	20.31 (18.87, 22.01)	20.50 (18.99, 22.46)	20.96 (19.18, 23.24)
Overweight[ad]	1640 (3.3)	2341 (4.2)	2591 (5.5)	3561 (7.5)	4819 (11.4)
Obesity[ad]	160 (0.3)	291 (0.5)	303 (0.6)	460 (1.0)	1105 (2.6)
Systolic blood pressure (mmHg)[bc]	110.00 (100.00, 120.00)	110.00 (100.00, 118.00)	110.00 (100.00, 120.00)	110.00 (101.00, 120.00)	113.00 (105.00, 122.00)
Diastolic blood pressure (mmHg)[bc]	70.00 (62.00, 75.00)	70.00 (62.00, 76.00)	70.00 (62.00, 78.00)	70.00 (64.00, 78.00)	72.00 (67.00, 80.00)
Elevated blood pressure[ad]	1074 (2.2)	1329 (2.4)	1904 (4.0)	1713 (3.6)	2211 (5.2)
Forced vital capacity (ml)[bc]	3200.00 (2640.00, 3900.00)	3000.00 (2400.00, 3737.00)	3100.00 (2500.00, 3911.00)	3172.00 (2526.00, 3964.00)	3265.00 (2636.00, 4048.00)
Sit-and-reach (cm)[bc]	10.00 (5.00, 14.90)	13.20 (8.70, 18.00)	13.00 (8.30, 17.80)	13.40 (8.50, 18.00)	13.60 (8.40, 18.60)
50-m dash (s)[bc]	8.20 (7.50, 9.30)	8.50 (7.50, 9.50)	8.60 (7.50, 9.60)	8.60 (7.60, 9.60)	8.70 (7.70, 9.80)
Standing long jump (cm)[bc]	205.00 (174.00, 235.00)	197.00 (170.00, 230.00)	195.00 (168.00, 230.00)	190.00 (165.00, 223.00)	187.00 (162.00, 220.00)
Body muscle strength (number)					
Pull-ups (boys)[bc]	8.00 (5.00, 12.00)	6.00 (3.00, 10.00)	4.00 (2.00, 7.00)	4.00 (2.00, 7.00)	3.00 (1.00, 7.00)
1-min sit-ups (girls)[bc]	35.00 (28.00, 41.00)	32.00 (26.00, 38.00)	29.00 (23.00, 35.00)	30.00 (25.00, 36.00)	31.00 (25.00, 37.00)
Endurance running (s)					
1000-m running (boys)[bc]	241.00 (226.80, 260.30)	251.20 (235.00, 273.00)	255.00 (236.50, 278.05)	260.10 (241.00, 284.50)	270.70 (247.37, 301.40)
800-m running (girls)[bc]	241.70 (226.40, 260.00)	250.50 (235.00, 270.00)	253.00 (236.70, 273.10)	253.90 (237.50, 273.40)	262.30 (241.67, 287.00)
Physical fitness indicator[bc]	−0.16 (−2.39, 1.96)	−1.12 (−3.42, 1.07)	−1.45 (−3.77, 0.78)	−1.56 (−3.95, 0.72)	−1.99 (−4.71, 0.56)

[a]Data are n (%). [b]Data are median (IQR). [c]Significant trends tested by the Jonckheere-Terpstra trend test ($P < 0.001$). [d]Significant trends tested by the Cochran-Armitage trend test ($P < 0.001$).

Table 1: **Basic characteristics, nutritional status, blood pressure, and physical fitness in Chinese college students aged 19–22 years of the Chinese National Survey on Students' Constitution and Health from 2000 to 2019.**

in 2019. The results of trends and associations using the Chinese standards to define OWOB were similar to those described above (Supplementary Fig. S2 and Tables S6 and S7).

Provincial distribution of physical fitness, OWOB, EBP, and comorbidity

Provincial trends presented that college students in northeastern China experienced the fastest decline in physical fitness from 2000 to 2019, accompanied by the largest increases in the burden of OWOB, EBP, and comorbidity (Fig. 3, Supplementary Tables S8 and S9). The provinces with the greatest declines in PFI were Heilongjiang and Jilin, with medians dropping from 0.86 and 1.07 in 2000 to −4.97 and −4.17 in 2019, respectively. Inner Mongolia showed the fastest increase in OWOB prevalence, rising from 4.6% in 2000 to 19.9% in 2019. Heilongjiang exhibited the most rapid rise in the prevalence of EBP, increasing from 4.5% in 2000 to 19.0% in 2019. The fastest increases in comorbidity prevalence were observed in Heilongjiang and Jilin, which rose from 0.8% and 0.1% in 2000 to 5.1% and 4.3% in 2019, respectively.

Associations of physical fitness with the prevalence of OWOB, EBP, and comorbidity

The five surveys from 2000 to 2019 all revealed that the prevalence of OWOB, EBP, and comorbidity increased as the level of PFI decreased among college students, with those at low-level PFI showing the most rapid growth, rising from 6.0%, 2.0%, and 0.5% in 2000 to 24.3%, 7.1%, and 3.8% in 2019, respectively (Fig. 2 and Supplementary Table S4). Mixed-effects logistic regression models supported that decreasing PFI levels were significantly associated with the increasing prevalence of OWOB, EBP, and comorbidity, and such associations were strongest in 2019, when ORs (95% *CI*) for OWOB, EBP, and comorbidity in college students with low-level PFI were 4.51 (3.98, 5.11), 1.48 (1.20, 1.81), and 8.49 (5.38, 13.41), compared to those with high-level PFI (Fig. 4 and Supplementary Table S5). Generalized linear mixed-effects models demonstrated the L-shaped curves

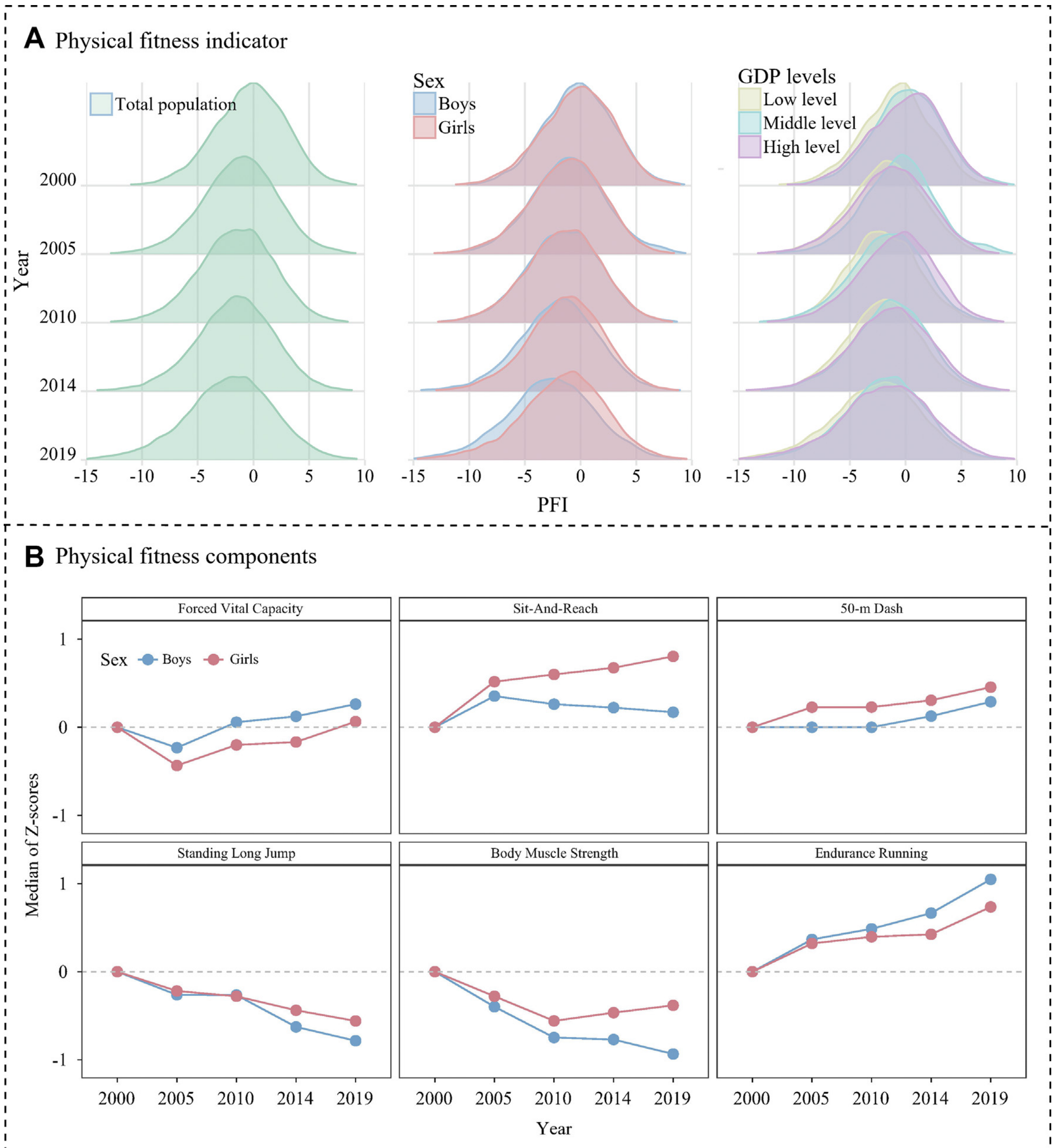

Fig. 1: Trends in physical fitness among Chinese college students from 2000 to 2019. A: trends in physical fitness indicator; B: trends in physical fitness components. Notes: Jonckheere-Terpstra trend test showed significant trends by years in all groups ($P < 0.001$); GDP = Gross domestic product; PFI = Physical fitness indicator.

for the dose-response relationships of PFI with the prevalence of OWOB, EBP, and comorbidity, among which the associations were stronger in boys than in girls, and the strength of associations was similar across the three economic regions (Fig. 4). The associations of physical fitness components with OWOB and EBP were presented in Supplementary Table S10, with all components, except for FVC, showing that a higher level was associated with a lower prevalence of OWOB and EBP. When using the Chinese standards to define OWOB, the associations were similar to those described above (Supplementary Fig. S3 and Table S7).

Provincial PAF displayed that when improving the PFI levels from low to middle-low or above, college students in southwest provinces, including Guizhou (OWOB: 37.3% [31.4%–43.3%]; EBP: 11.0% [–1.6%–23.6%]; comorbidity:

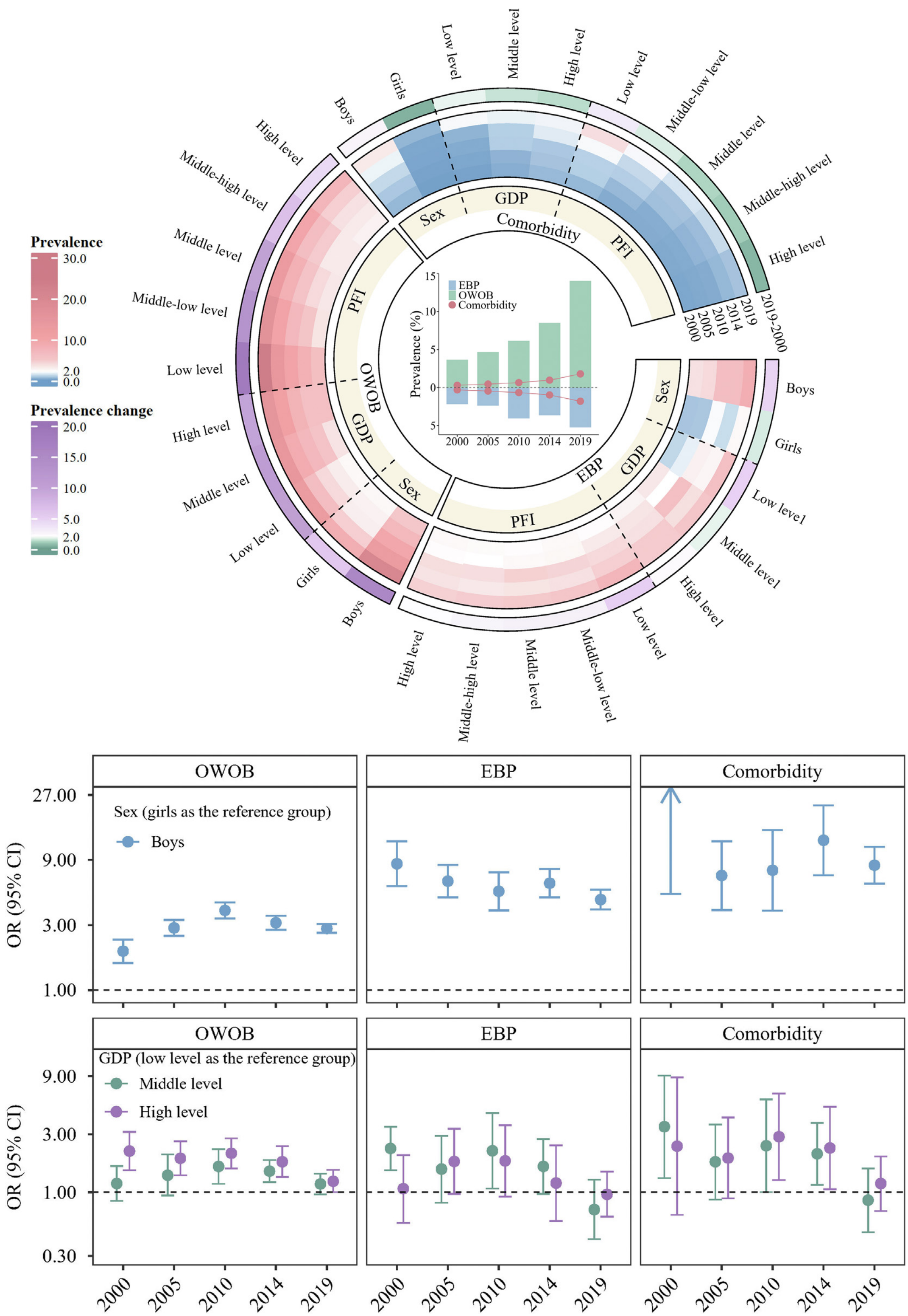

Fig. 2: Trends in prevalence of overweight and obesity, elevated blood pressure, and comorbidity among Chinese college students from 2000 to 2019. Notes: Cochran-Armitage trend test showed increasing prevalence by years in all groups ($P < 0.001$); Regression models were adjusted for basic demographic variables and cluster effects of colleges; EBP = Elevated blood pressure; GDP = Gross domestic product; OWOB = Overweight and obesity; PFI = Physical fitness indicator.

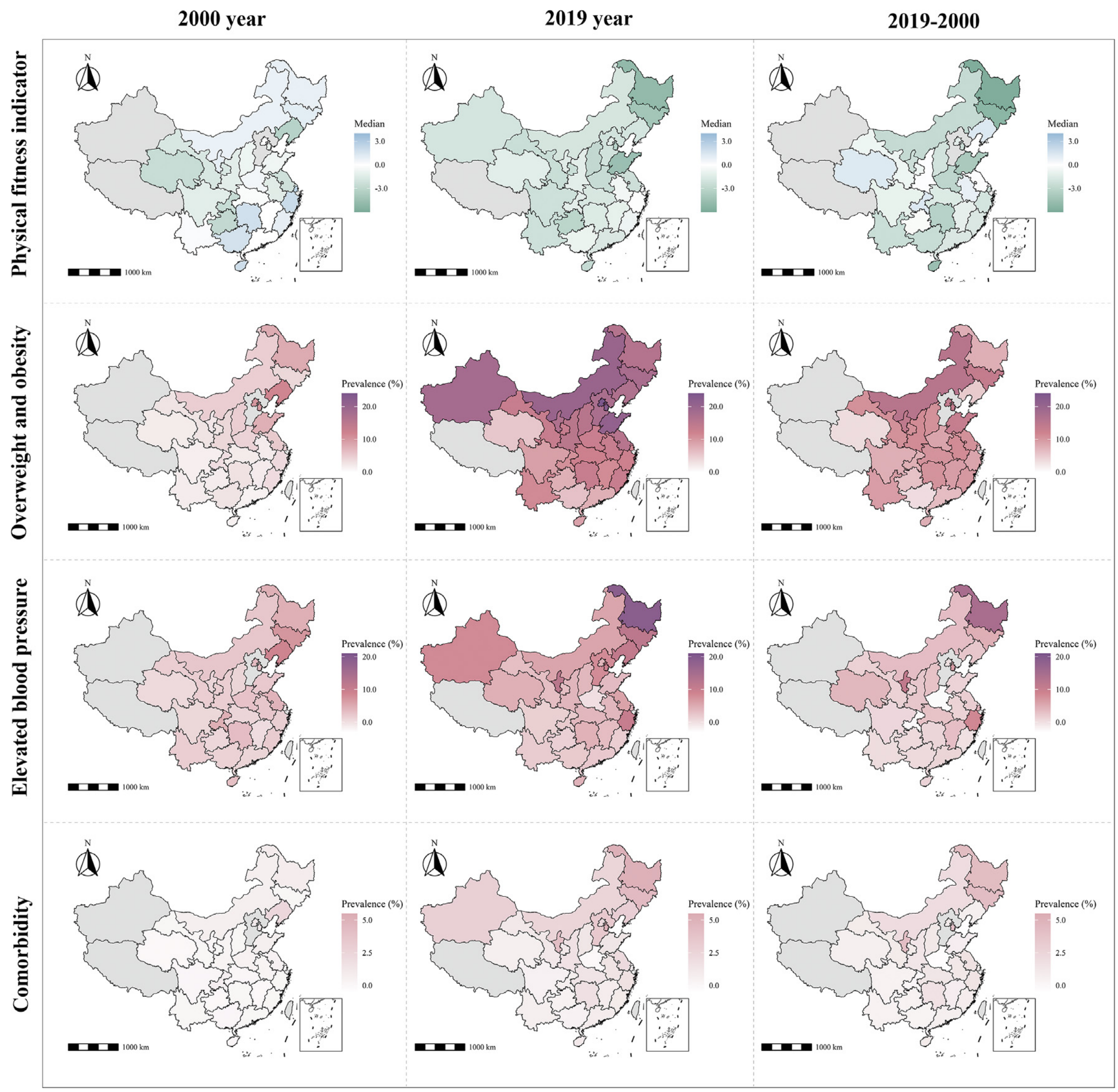

Fig. 3: Provincial distribution of physical fitness, overweight and obesity, elevated blood pressure, and comorbidity.

75.5% [58.4%–92.6%]), Sichuan (OWOB: 27.9% [20.8%–35.0%]; EBP: 4.6% [−5.1%–14.4%]; comorbidity: 61.0% [32.3%–89.8%]), and Yunnan (OWOB: 22.9% [18.7%–27.1%]; EBP: 2.6% [−4.2%–9.3%]; comorbidity: 26.0% [5.4%–46.6%]), exhibited most reductions in OWOB, EBP, and comorbidity (Fig. 5). Results of sensitive analyses were similar to those described above (Supplementary Fig. S4).

Discussion

To our knowledge, it has been the first research using nationwide monitoring data to describe the trends in physical fitness and prevalence of OWOB, EBP, and comorbidity among college students since the 21st century, accordingly filling the critical gap in health data for this population and holding monumental significance for drawing concern on cardiovascular health in young adults. We mainly observed that from 2000 to 2019, the prevalence of OWOB, EBP, and comorbidity among Chinese college students aged 19–22 years exhibited a persistent increase, accompanied by a consistent deterioration in physical fitness, with the situation being the most severe in northeastern provinces. Boys presented a more severe burden of OWOB, EBP, and comorbidity, as well as poorer physical fitness, while health inequalities among students from different economic regions gradually diminished. There were typical dose-response relationships of physical fitness with the prevalence of OWOB, EBP, and comorbidity,

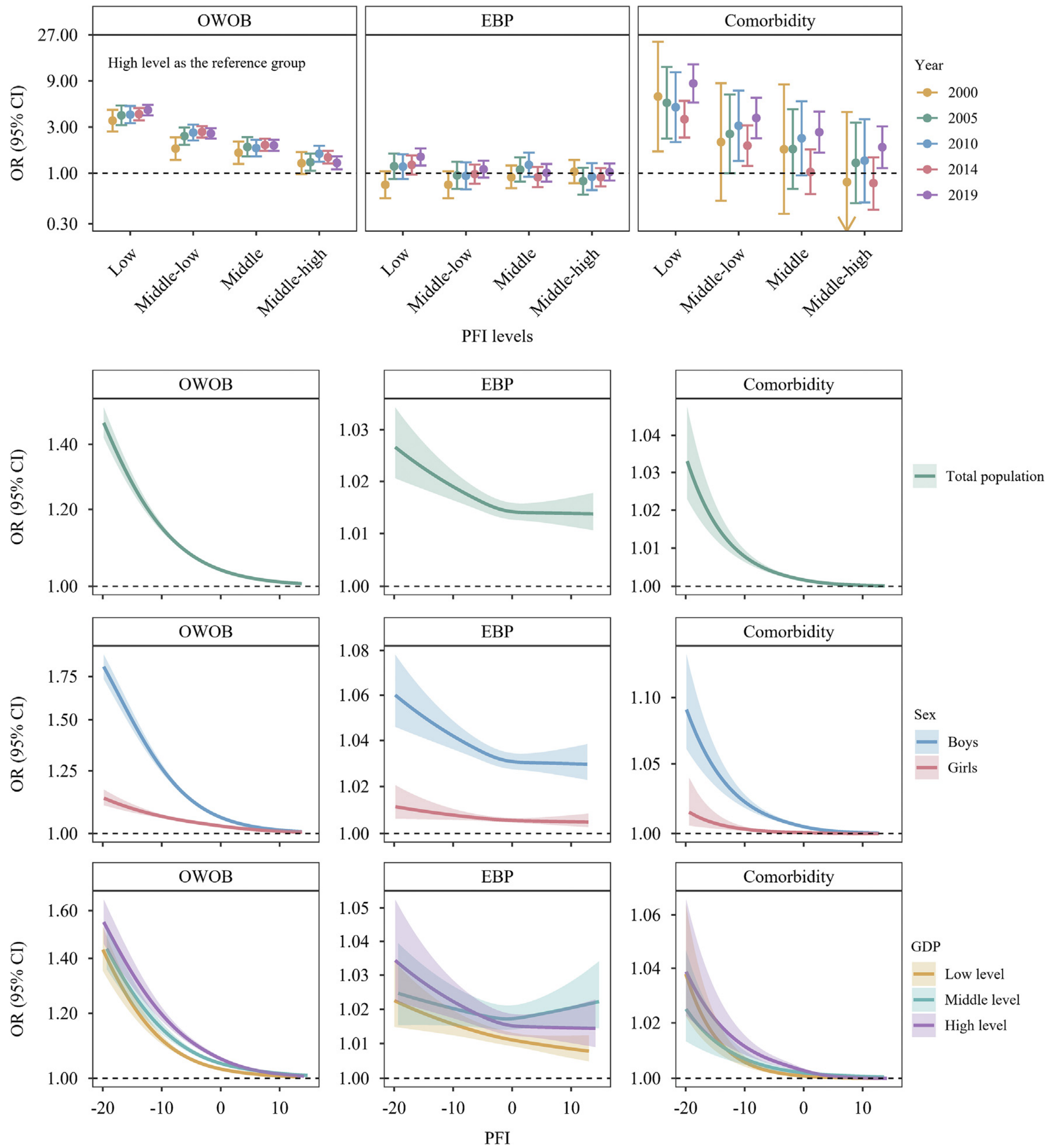

Fig. 4: Associations of physical fitness with the prevalence of overweight and obesity, elevated blood pressure, and comorbidity among Chinese college students. Notes: Regression models were adjusted for basic demographic variables and cluster effects of colleges; The shaded area around the curves represented the 95% CI; CI = Confidence interval; EBP = Elevated blood pressure; GDP = Gross domestic product; OR = Odds ratio; OWOB = Overweight and obesity; PFI = Physical fitness indicator.

which became stronger in 2019. Furthermore, we identified L-shaped associations of physical fitness with the prevalence of OWOB, EBP, and comorbidity, with stronger linkages observed in boys and in southwest provinces.

The rapid surge in the prevalence of OWOB and EBP among college students corroborated the severe burden of cardiovascular risk factors in this population, corresponding to the critical issue of cardiovascular disease onset at younger ages. It was worth noting that growing evidence indicated the incidence of cardiovascular disease has either been stagnating or increasing among young individuals, in contrast to the observed decline in the incidence of cardiovascular disease in adults aged >50 years.[24] Previous studies conducted in the United States and Australia have revealed an

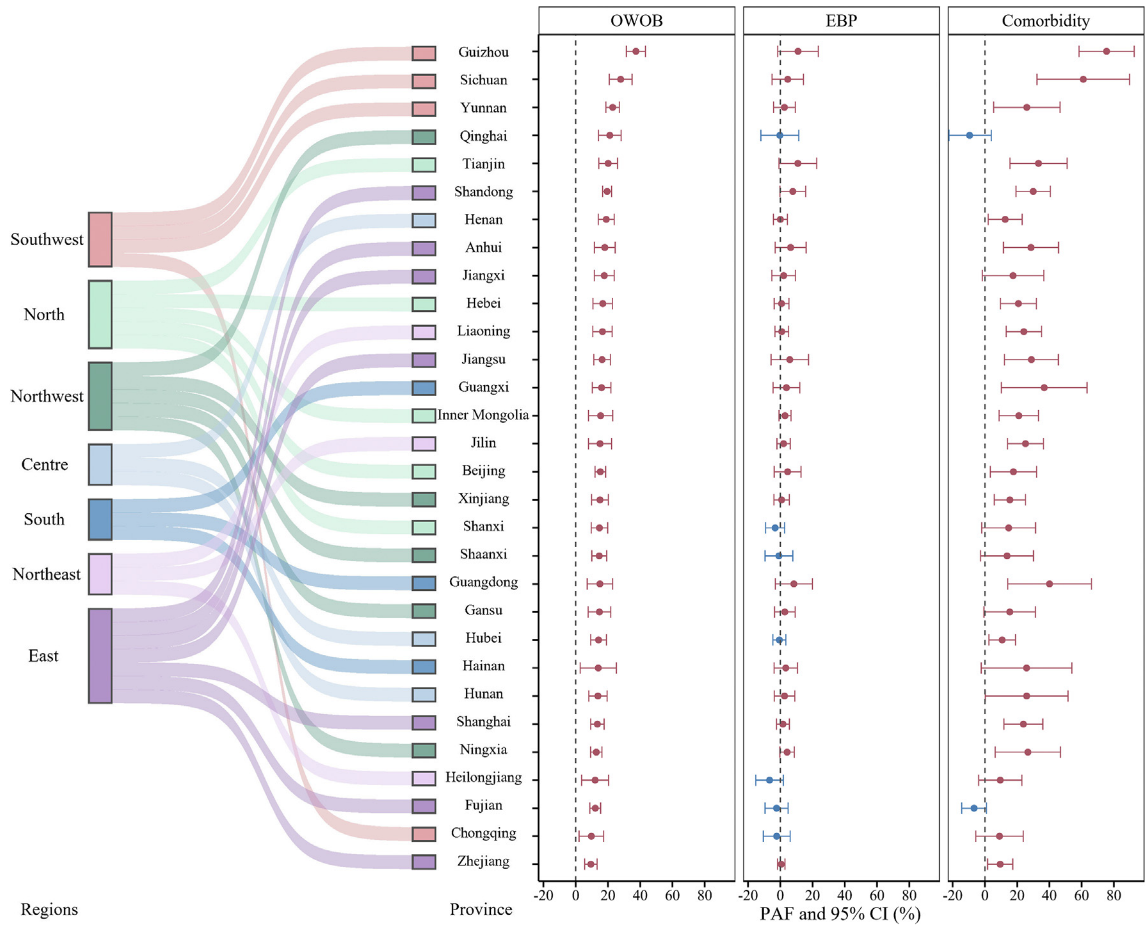

Fig. 5: Provincial population attributable fraction of low-level physical fitness for the prevalence of overweight and obesity, elevated blood pressure, and comorbidity. Notes: Models were adjusted for basic demographic variables and cluster effects of colleges; CI = Confidence interval; EBP = Elevated blood pressure; GDP = Gross domestic product; OR = Odds ratio; OWOB = Overweight and obesity; PAF = Population Attributable Fraction.

increasing burden of OWOB among college students, whereas the prevalence remained relatively lower in Asian population, highlighting the concerning issue of cardiovascular health among college students worldwide.[25,26] However, our study demonstrated that among 100 Chinese college students in 2019, there would be 14 students with OWOB, five students with EBP, and two students with comorbidity of OWOB and EBP, implying that managing cardiovascular risk factors should be initiated as early as possible to reduce risk of cardiovascular disease and enhance overall life expectancy in the future.[27] On the one hand, partial cardiovascular risk factors originated during childhood and adolescence, which could be reversed in time by addressing unhealthy lifestyles in colleges.[28] On the other hand, the college stage was a transitional phase in society, during which significant changes in mindset and behaviors associated with cardiovascular risk factors usually persisted into later adulthood.[2,29] In addition, consistent with previous research,[30] we observed that the risk of EBP was significantly increasing among individuals with OWOB, with the prevalence of EBP exceeding 10.0% in college students with OWOB in 2019. Potential mechanisms linking OWOB to EBP could be divided into biological and behavioral mechanisms, including insulin-mediated stimulation of the sympathetic nervous system, renin-angiotensin-aldosterone system activity, endothelial and vascular dysfunction, and shared unhealthy lifestyle behaviors.[12,31–33] Endogenous estrogen, favorable for lipid metabolism through estrogen signaling pathways, was the biological factor for the sex differences in the prevalence of OWOB, EBP, and comorbidity.[34] Additionally, poor eating habits, a higher prevalence of smoking, and more sleep disorders contributed to the higher risks of cardiovascular risk factors in boys as well.[34] Diminished differences in the burden of OWOB, EBP, and comorbidity among different economic regions indicated that with the economy's growth, each area should pay equal attention and take interventions to address the increasing burden of cardiovascular risk factors in young adults.

Consistent with previous findings in children and adolescents,[13,18] our study supported that lower physical fitness levels were significantly associated with higher risks of OWOB, EBP, and comorbidity among college students. Stronger associations in 2019 implicated that physical fitness could be considered a worthwhile health determinant to be intervened, contributing to alleviating the burden of cardiovascular risk factors among young adults.[35] The pathways of cardiovascular functionality by physical fitness might be attributed to the reduction of low-grade inflammatory markers and homocysteine, the alleviation of arterial stiffness, the augmentation of skeletal muscle capillarization, and the enhancement of endothelial nitric oxide synthase content.[35,36] However, the physical fitness of college students has shown a continued trend of deterioration since the 21st century. It was of concern that ER, MS, and SLJ exhibited the most rapid decline in both sexes, with evidence from longitudinal studies proving that cardiorespiratory and muscular endurance in young adults were strong predictors of cardiovascular disease in late adulthood.[37,38] Prior research has demonstrated that physical fitness in Chinese children and adolescents aged 7–18 years declined from 1995 to 2014, with ER, MS, and SLJ declining the most, which might cause similar trends among college students in our study.[18] The absence of an active school environment, attributed to the crowded academic curriculum and the fragmentation of physical education content, has hindered the improvement of physical fitness among school-aged individuals.[39,40] The disappearance of recess exercise and the reduced duration and frequency of physical education lessons in colleges pose significant challenges, which meant that college students needed greater physical literacy and social support to achieve favorable exercise.[41,42]

The sex-specific associations of physical fitness with OWOB, EBP, and comorbidity observed in our study aligned with previous research. On the one hand, cardiac autonomic function, which integrated sympathetic and parasympathetic signals to regulate cardiac function, has exhibited greater sensitivity to cardiorespiratory fitness in boys.[43] On the other hand, estradiol and progesterone in girls conferred more protective effects on cardiovascular health, potentially mitigating the impact of physical fitness on cardiovascular outcomes.[44,45] Reginal differences in associations of physical fitness with OWOB, EBP, and comorbidity were worthy of attention as well. The higher PAF observed in Guizhou, Sichuan, and Yunnan provinces implicated that enhancing physical fitness could gain more excellent benefits in reducing the cardiovascular disease burden in southwestern China, characterized by high population density, limited economic development, and challenging transportation infrastructure.[46] Furthermore, these regions experience minimal seasonal temperature variations, enjoy warm winters and mild summers, and boast abundant green spaces,[47] creating favorable geographic and climatic conditions for outdoor exercise, which might explain why individuals in these areas are more likely to benefit from physical fitness in terms of health. Additionally, although the trends in physical fitness in several provinces appeared to align with the trends in the prevalence of OWOB and EBP, statistical tests indicated that the associations were not significant, supporting that improvements in physical fitness did not increase the cardiovascular risks. These findings have underscored the importance of targeted interventions to enhance physical fitness, particularly in resource-constrained areas and countries, as a critical strategy to promote cardiovascular health among college students.

According to the national population census in China, the proportion of undergraduates among the population aged 19–22 years has increased rapidly from 4.1% in 2000 to 28.1% in 2020, mapping out the fact that the expansion of higher education has rendered college students as a prominent demographic within the population of young adults.[48] While economic and social development brought convenience, it also exposed college students to increasing temptations, including high-calorie and low-nutrient fast food, prolonged sedentary and screen time, and disturbed sleep rhythms, creating an inactive macro-environment causing declining physical fitness and rising cardiovascular risks.[16] Therefore, it was urgently necessary to reverse the inactive environment to promote college students' physical fitness and achieve primary prevention of cardiovascular disease. A recent systematic review implicated that quality-based physical education interventions, including physical education specialist-led lessons and circuit training, were beneficial for health-related physical fitness and fundamental motor skills regardless of the duration and frequency of physical education lessons.[49] In addition, conceptual physical education, utilizing text materials and classroom sessions to teach kinesiology concepts and self-management skills, could be converted from an elective to a required college course to build motivation and promote out-of-campus physical activity in college students.[50] Additionally, resistance and aerobic training were suggested to enhance muscular and cardiovascular fitness by increasing motor neurons, reducing sympathetic activity, and increasing vagal tone at rest.[51,52] Furthermore, given that the existing national health monitoring systems mainly targeted residents and students from primary and secondary schools, it is essential to establish and improve the college-based physical examination systems at both national and international levels, achieving the long-term assessment of college students' physical fitness and cardiovascular function.[53,54]

There were some limitations that remained. First, the CNSSCH surveys were successive cross-sectional designs rather than prospective cohort studies, so our research could portray trends and associations but could not prove causality. Second, blood pressure was measured three times at a single visit in CNSSCH surveys, failing to meet the criteria of clinical guidelines requiring measurements at three visits to diagnose hypertension, which was very difficult to achieve in a large-sample study. Third, among the six core items of physical fitness, two were tested differently between boys (pull-ups and 1000-m running) and girls (1-min sit-ups and 800-m running), which might partially account for the observed sex differences. Yet, most Asian countries existed sex differences in the testing methods for child and adolescent physical fitness,[55] so there was a need to promote testing methods that could be applied to the whole population, such as handgrip strength and 20-m shuttle run.[56] Forth, despite being the most nationally representative survey covering the most colleges in 30 provinces in China, the CNSSCH surveys only selected 2–4 provincial colleges in each province, so it could not reflect the physical fitness, OWOB, and EBP of postgraduate students, as well as students from colleges under the administration of the Ministry of Education. In addition, since we were unable to obtain population data for Chinese college students aged 19–22 years, we could not perform weighted estimation of the prevalence in this study to achieve more accurate results. Fifth, although the PAF calculation was widely used in prevalence studies, it was important to note that, strictly speaking, PAF should be calculated based on risk ratios.[57] We used ORs to estimate PAF in this study instead, and further validation in longitudinal studies was needed to obtain unbiased estimates. Finally, although we have adjusted for the basic demographic variables and cluster effects of colleges in analyzing the associations, there were other potential covariates not included, such as physical activity, diets, and other lifestyle factors. Future studies should measure these variables and apply causal directed acyclic graphs to better identify and adjust additional confounders.

In summary, since the 21st century, there has been a concerning trend of declining physical fitness and an alarming rise in the prevalence of OWOB, EBP, and comorbidity among college students. During this period, the associations of physical fitness with the prevalence of OWOB, EBP, and comorbidity remained strong, showing L-shaped dose-response relationships. There is a pressing need to enhance the quality of physical education lessons in colleges, integrate endurance and aerobic training into the content of the physical education curriculum, foster physical activity literacy and develop healthy lifestyles in college students to improve physical fitness and release the burden of cardiovascular risk factors. Most importantly, it is essential to increase the focus on physical fitness and cardiovascular health among college students and establish a college-based physical examination system to achieve long-term assessment of their cardiovascular function.

Contributors

SC and YS conceptualized and designed the study. SC completed the statistical analyses, drafted the initial manuscript, and reviewed and revised the manuscript. YZ, ZC, YL, JD, JL, TH, ZS, YD, and JM contributed to interpretation of the data and reviewed and revised the manuscript. YS accessed and verified the data, and was responsible for the decision to submit the manuscript. All authors approved the final manuscript as submitted and agreed to be accountable for all aspects of the work.

Data sharing statement

All data in this article can be shared. Requests with appropriate ethics board approvals and study protocols will be assessed by the Institute of Child and Adolescent Health, Peking University (Beijing, China). To request access please contact the corresponding author by email: songyi@bjmu.edu.cn.

Editor note

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Declaration of interests

We declare no competing interests.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lanwpc.2025.101560.

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